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APPLICATION FOR LETTERS PATENT

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**Method And Apparatus For Testing Semiconductor
Circuitry For Operability And Method Of Forming
Apparatus For Testing Semiconductor Circuitry For
Operability**

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1 **TECHNICAL FIELD**

2 This invention relates to methods for testing semiconductor
3 circuitry for operability, and to constructions and methods of forming
4 testing apparatus for operability testing of semiconductor circuitry.

5
6 **BACKGROUND OF THE INVENTION**

7 This invention grew out of the needs and problems associated with
8 multi-chip modules, although the invention will be applicable in other
9 technologies associated with circuit testing and testing apparatus
10 construction. Considerable advancement has occurred in the last fifty
11 years in electronic development and packaging. Integrated circuit density
12 has and continues to increase at a significant rate. However by the
13 1980's, the increase in density in integrated circuitry was not being
14 matched with a corresponding increase in density of the interconnecting
15 circuitry external of circuitry formed within a chip. Many new
16 packaging technologies have emerged, including that of "multichip
17 module" technology.

18 In many cases, multichip modules can be fabricated faster and
19 more cheaply than by designing new substrate integrated circuitry.
20 Multichip module technology is advantageous because of the density
21 increase. With increased density comes equivalent improvements in
22 signal propagation speed and overall device weight unmatched by other
23 means. Current multichip module construction typically consists of a
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1 printed circuit board substrate to which a series of integrated circuit
2 components are directly adhered.

3 Many semiconductor chip fabrication methods package individual
4 dies in a protecting, encapsulating material. Electrical connections are
5 made by wire bond or tape to external pin leads adapted for plugging
6 into sockets on a circuit board. However, with multichip module
7 constructions, non-encapsulated chips or dies are secured to a substrate,
8 typically using adhesive, and have outwardly exposed bonding pads.
9 Wire or other bonding is then made between the bonding pads on the
10 unpackaged chips and electrical leads on the substrate.

11 Much of the integrity/reliability testing of multichip module dies
12 is not conducted until the chip is substantially complete in its
13 construction. Considerable reliability testing must be conducted prior to
14 shipment. In one aspect, existing technology provides temporary wire
15 bonds to the wire pads on the die for performing the various required
16 tests. However, this is a low-volume operation and further requires the
17 test bond wire to ultimately be removed. This can lead to irreparable
18 damage, thus effectively destroying the chip.

19 Another prior art test technique uses a series of pointed probes
20 which are aligned to physically engage the various bonding pads on a
21 chip. One probe is provided for engaging each bonding pad for
22 providing a desired electrical connection. One drawback with such
23 testing is that the pins undesirably on occasion penetrate completely
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1 through the bonding pads, or scratch the bonding pads possibly leading
2 to chip ruin.

3 It would be desirable to overcome these and other drawbacks
4 associated with testing semiconductor circuitry for operability.

5 6 BRIEF DESCRIPTION OF THE DRAWINGS

7 Preferred embodiments of the invention are described below with
8 reference to the following accompanying drawings.

9 Fig. 1 is a diagrammatic representation of a fragment of a
10 substrate processed in accordance with the invention.

11 Fig. 2 is a view of the Fig. 1 substrate fragment at a processing
12 step subsequent to that shown by Fig. 1.

13 Fig. 3 is a perspective view of the Fig. 2 substrate fragment.

14 Fig. 4 is a view of the Fig. 1 substrate fragment at a processing
15 step subsequent to that shown by Fig. 2.

16 Fig. 5 is a view of the Fig. 1 substrate fragment at a processing
17 step subsequent to that shown by Fig. 4.

18 Fig. 6 is a perspective view of the Fig. 5 substrate fragment.

19 Fig. 7 is a view of the Fig. 1 substrate fragment at a processing
20 step subsequent to that shown by Fig. 5.

21 Fig. 8 is a view of the Fig. 1 substrate fragment at a processing
22 step subsequent to that shown by Fig. 7.

23 Fig. 9 is a perspective view of a substrate fragment processed in
24 accordance with the invention.

1 Fig. 10 is a view of a substrate fragment processed in accordance
2 with the invention.

3 Fig. 11 is a view of the Fig. 10 substrate fragment at a
4 processing step subsequent to that shown by Fig. 10.

5 Fig. 12 is a view of the Fig. 10 substrate fragment at a
6 processing step subsequent to that shown by Fig. 11.

7 Fig. 13 is a view of the Fig. 10 substrate fragment at a
8 processing step subsequent to that shown by Fig. 12.

9 Fig. 14 is a view of the Fig. 13 substrate in a testing method in
10 accordance with the invention.

11 Fig. 15 is a view of a substrate fragment processed in accordance
12 with the invention.

13 Fig. 16 is a view of the Fig. 15 substrate fragment at a
14 processing step subsequent to that shown by Fig. 15.

15 Fig. 17 is a view of the Fig. 15 substrate fragment at a
16 processing step subsequent to that shown by Fig. 16.

17 Fig. 18 is a view of a substrate fragment processed in accordance
18 with the invention.

19 Fig. 19 is a view of the Fig. 18 substrate fragment at a
20 processing step subsequent to that shown by Fig. 18.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

This disclosure of the invention is submitted in furtherance of the constitutional purposes of the U.S. Patent Laws "to promote the progress of science and useful arts" (Article 1, Section 8).

In accordance with one aspect of the invention, a method of engaging electrically conductive test pads on a semiconductor substrate having integrated circuitry for operability testing thereof comprises the following sequential steps:

providing an engagement probe having an outer surface comprising a grouping of a plurality of electrically conductive projecting apexes positioned in proximity to one another to engage a single test pad on a semiconductor substrate;

engaging the grouping of apexes with the single test pad on the semiconductor substrate; and

sending an electric signal between the grouping of apexes and test pad to evaluate operability of integrated circuitry on the semiconductor substrate.

In accordance with another aspect of the invention, a method of forming a testing apparatus for engaging electrically conductive test pads on a semiconductor substrate having integrated circuitry for operability testing thereof, comprises the following steps:

providing a locally substantially planar outer surface of a first material on a semiconductor substrate;

1 providing a layer of second material atop the substantially planar
2 outer surface of first material, the second material being capable of
3 substantially masking the underlying first material;

4 patterning and etching the layer of second material to selectively
5 outwardly expose the first material and define a grouping of discrete
6 first material masking blocks, the discrete first material masking blocks
7 of the grouping having respective centers, the respective centers of the
8 grouping being positioned in sufficient proximity to one another such
9 that the centers of the grouping fall within confines of a given single
10 test pad which the apparatus is adapted to electrically engage;

11 forming projecting apexes beneath the masking blocks at the
12 masking block centers, the projecting apexes forming a group falling
13 within the confines of the given single test pad of which the apparatus
14 is adapted to electrically engage;

15 removing the discrete first material masking blocks from the
16 substrate after the exposing step; and

17 rendering the projecting apexes electrically conductive.

18 In accordance with yet another aspect of the invention, a testing
19 apparatus for engaging electrically conductive test pads on a
20 semiconductor substrate having integrated circuitry for operability testing
21 thereof comprises:

22 a test substrate; and

23 an engagement probe projecting from the test substrate to engage
24 a single test pad on a semiconductor substrate having integrated

1 circuitry formed in the semiconductor substrate, the engagement probe
2 having an outer surface comprising a grouping of a plurality of
3 electrically conductive projecting apexes positioned in sufficient proximity
4 to one another to collectively engage the single test pad.

5 The discussion proceeds initially with description of methods for
6 forming testing apparatus in accordance with the invention, and to
7 testing apparatus construction. Fig. 1 illustrates a semiconductor
8 substrate fragment 10 comprised of a bulk substrate 12, preferably
9 constituting monocrystalline silicon. Substrate 12 includes a locally
10 substantially planar outer surface 14 comprised of a first material. In
11 a preferred and the described embodiment, the first material constitutes
12 the material of bulk substrate 12, and is accordingly silicon. A
13 layer 16 of second material is provided atop the planar outer
14 surface 14 of the first material. The composition of the second
15 material is selected to be capable of substantially masking the underlying
16 first material from oxidation when the semiconductor substrate is
17 exposed to oxidizing conditions. Where the underlying first material
18 comprises silicon, an example and preferred second material is Si_3N_4 .
19 A typical thickness for layer 16 would be from about 500 Angstroms to
20 about 3000 Angstroms, with about 1600 Angstroms being preferred.

21 Referring to Figs. 2 and 3, second material layer 16 is patterned
22 and etched to selectively outwardly expose the first material and define
23 a grouping of discrete first material masking blocks 18, 20, 24 and 26.
24 For purposes of the continuing discussion, the discrete first material

1 masking blocks of the grouping have respective centers. The lead lines
2 in Fig. 2 depicting each of blocks 18, 20, 22 and 24 point directly to
3 the lateral centers of the respective blocks. The respective centers of
4 the grouping are positioned in sufficient proximity to one another such
5 that the centers of the grouping will fall within the confines of a given
6 single test pad of which the apparatus is ultimately adapted to
7 electrically engage for test. Such will become more apparent from the
8 continuing discussion.

9 As evidenced from Fig. 3, masking blocks 18, 20, 24 and 26 are
10 patterned in the form of lines or runners integrally joined with other
11 masking blocks/lines 28, 30, 32 and 34. The blocks/lines interconnect
12 as shown to form first and second polygons 36, 38, with polygon 38
13 being received entirely within polygon 36. Polygons 36 and 38
14 constitute a grouping 41 masking blocks the confines of which fall
15 within the area of a given single test pad of which the apparatus is
16 ultimately adapted to electrically engage for test.

17 Referring to Fig. 4, semiconductor substrate 10 is exposed to
18 oxidizing conditions effective to oxidize the exposed outer surfaces of
19 first material. Such oxidizes a sufficient quantity of first material in a
20 somewhat isotropic manner to form projecting apexes 40, 42, 44 and 46
21 forming a group 43 which, as a result of the patterning of the
22 preferred nitride layer 16, fall within the confines of the given single
23 test pad of which the apparatus is adapted to electrically engage. Such
24 produces the illustrated oxidized layer 48. Example oxidizing conditions

1 to produce such effect would be a wet oxidation, whereby oxygen is
2 bubbled through H_2O while the substrate is exposed to $950^{\circ}C$.

3 Referring to Fig. 5, the oxidized first material 48 is stripped from
4 the substrate. Example conditions for conducting such stripping would
5 include a hot H_3PO_4 wet etch. Thereafter, the discrete first material
6 masking blocks 18, 20, 24, 26, 28, 30, 32 and 34 are removed from the
7 substrate. An example condition for such stripping in a manner which
8 is selective to the underlying silicon apexes include a room temperature
9 HF wet etch. Thus referring to Fig. 6, the steps of patterning and
10 etching, exposing, and stripping form projecting apexes beneath the
11 masking blocks at the masking block centers, such projecting
12 apexes being numbered 40, 42, 44, 46, 48, 50, 52 and 54, which are in
13 the form of multiple knife-edge lines. The knife-edge lines interconnect
14 to form the illustrated polygons 36 and 38. The apexes and
15 correspondingly knife-edged or pyramid formed polygons are sized and
16 positioned in sufficient proximity to fall within the confines of a single
17 test pad of which the apparatus is adapted to engage, as will be more
18 apparent from the continuing discussion.

19 Other ways could be utilized to form projecting apexes beneath
20 the masking blocks at the masking block centers. As but one example,
21 a wet or dry isotropic etch in place of the step depicted by Fig. 4
22 could be utilized. Such etching provides the effect of undercutting
23 more material from directly beneath the masking blocks to create
24 apexes, as such areas or regions have greater time exposure to etching.

1 Referring again to Fig. 5, the oxidation step produces the
2 illustrated apexes which project from a common plane 56. For purposes
3 of the continuing discussion, the apexes can be considered as having
4 respective tips 58 and bases 60, with bases 60 being coincident with
5 common plane 56. For clarity, tip and base pairs are numbered only
6 with reference to apexes 40 and 42. Bases 60 of adjacent projecting
7 apexes are spaced from one another a distance sufficient to define a
8 penetration stop plane 62 therebetween. Example spacings between
9 apexes would be 1 micron, while an example length of an individual
10 stop plane would be from 3 to 10 microns. The function of
11 penetration stop plane 62 will be apparent from the continuing
12 discussion. A tip 58 and base 60 are provided at a projecting distance
13 apart which is preferably designed to be about one-half the thickness
14 of the test pad which the given apparatus is adapted to engage.

15 Multiple oxidizing and stripping steps might be conducted to
16 further sharpen and shrink the illustrated projecting apexes. For
17 example and again with reference to Fig. 4, the illustrated construction
18 in such multiple steps would have layer 48 stripped leaving the
19 illustrated masking blocks in place over the apexes. Then, the substrate
20 would be subjected to another oxidation step which would further
21 oxidize substrate first material 12, both downwardly and somewhat
22 laterally in the direction of the apexes, thus likely further sharpening
23 the apexes. Then, the subsequently oxidized layer would be stripped
24

1 from the substrate, thus resulting in deeper, sharper projections relative
2 from a projecting plane.

3 Referring to Fig. 7, apex group 43 is covered a nitride masking
4 layer 64 and photopatterned. Referring to Fig. 8, silicon substrate 12
5 is then etched into around the masked projecting apexes to form a
6 projection 64 outwardly of which grouping 43 of the projecting apexes
7 project. The masking material is then stripped.

8 More typically, multiple groups of projecting apexes and
9 projections would be provided, with each being adapted to engage a
10 given test pad on a particular chip. Further tiering for producing
11 electrically contact-engaging probes might also be conducted. Fig. 9
12 illustrates such a construction having apex groups 43a and 43b formed
13 atop respect projection 64a and 64b. A typical projecting distance from
14 base 60 to tip 58 would be 0.5 microns, with a projection 64 being 100
15 microns deep and 50 microns wide. Projections 64a and 64b in turn
16 have been formed atop elongated projections 66a and 66b, respectively.
17 Such provides effective projecting platforms for engaging test pads as
18 will be apparent from the continuing discussion.

19 Next, the group of projecting apexes is rendered electrically
20 conductive, and connected with appropriate circuitry for providing a
21 testing function. The discussion proceeds with reference to Figs. 10-13
22 for a first example method for doing so. Referring first to Fig. 10, a
23 substrate includes a pair of projections 64c and 64d having respective
24 outwardly projecting apex groups 43c and 43d. A layer of photoresist

1 is deposited atop the substrate and patterned to provide photoresist
2 blocks 68 as shown. Photoresist applies atop a substrate as a liquid,
3 thus filling valleys in a substrate initially and not coating outermost
4 projections. Thus, the providing of photoresist to form blocks 68 is
5 conducted to outwardly exposed projecting apex groups 43c and 43d, as
6 well as selected area 70 adjacent thereto. Photoresist blocks 68 covers
7 selected remaining portions of the underlying substrate.

8 Referring to Fig. 11, electric current is applied to substrate 12 to
9 be effective to electroplate a layer of metal 72 onto outwardly exposed
10 projecting apex groupings 43c and 43d and adjacent area 70. An
11 example material for layer 72 would be electroplated Ni, Al, Cu, etc.
12 An example voltage and current where substrate 12 comprises silicon
13 would be 100V and 1 milliamp, respectively. Under such conditions,
14 photoresist functions as an effective insulator such that metal deposition
15 only occurs on the electrically active surfaces in accordance with
16 electroplating techniques. Photoresist is then stripped from the
17 substrate, leaving the Fig. 11 illustrated construction shown, which may
18 also include a desired conductive runner 74 formed atop bulk
19 substrate 12 between projections 64c and 64d.

20 The preferred material for metal layer 72 is platinum, due to its
21 excellent oxidation resistance. Unfortunately, it is difficult to directly
22 bond the typical copper or gold bonding wires to platinum.
23 Accordingly, preferably an intervening aluminum bonding site is provided.
24 Referring to Fig. 12, an aluminum or aluminum alloy layer 76 is

1 blanket deposited atop the substrate. A layer of photoresist is
2 deposited and patterned to provide photoresist masking blocks 78. The
3 substrate would then be subjected to an etch of the aluminum material
4 in a manner which was selective to the underlying platinum. Example
5 etching conditions would include a hot H_3PO_4 wet etch. Such leaves
6 resulting elevated bonding blocks 80 of aluminum atop which a bonding
7 wire 82 is conventionally bonded, as shown in Fig. 13.

8 The description proceeds with reference to Fig. 14 for utilizing
9 such an apparatus for conducting electrical tests of a chip. Fig. 14
10 illustrates the testing apparatus of Fig. 13 engaging a chip 85 which is
11 being tested. Chip 85 comprises a substrate portion 86 and outwardly
12 exposed bonding pads 88. Protecting or encapsulating material 90 is
13 provided such that substrate 86 and circuitry associated therewith is
14 protected, with only bonding pads 88 being outwardly exposed. Bonding
15 pads 88 have some thickness "A".

16 Substrate 12 comprises a test substrate having engagement
17 probes 64c and 64d projecting therefrom. Such include respective
18 electrically conductive apexes groups 43c and 43d positioned in
19 respective proximity to fall within the confines of and engage a single
20 test pad 88 on chip 85. Such apexes are engaged with the respective
21 test pads, as shown.

22 The illustrated projecting apexes actually project in to half-way
23 into the thickness of the bonding pads, a distance of approximately
24 on-half "A". The penetration stop surface 62 described with reference

1 to Fig. 5 provides a stopping point for preventing the projecting points
2 from extending further into bonding pads 88 than would be desired.
3 In connecting the testing apparatus to chip 85, pressure would be
4 monitored during engagement of the projecting tips relative to the
5 pads 88. At some point during the projection, the force or back
6 pressure against the testing apparatus would geometrically increase as
7 the penetration stop plane reaches the outer surface of the bonding
8 pads 88, indicating that full penetration had occurred. At this point,
9 the testing substrate and chip 85 would be effectively electrically
10 engaged. An electric signal would be sent between the respective
11 grouping of apexes and respective test pads in conventional testing
12 methods to evaluate operability of integrated circuitry formed within the
13 semiconductor substrate 85.

14 Reference is made to Figs. 15-17 for a description of an alternate
15 method of rendering projecting apexes electrically conductive.

16 Starting with Fig. 15, such are sectional views taken laterally
17 through projection 64a of Fig. 9. Referring to Fig. 16, an electrically
18 conductive nucleation layer 90 is blanket deposited atop the apexes and
19 substrate. An example material would be elemental nickel deposited by
20 sputter techniques. Photoresist is then applied and patterned as shown
21 to produce photoresist blocks 92. Thus, the nucleation layer coated
22 projecting apexes and selected area adjacent thereto is outwardly
23 exposed, while selected remaining nucleation layer coated portions of the
24 substrate are coated by resist blocks 92. At this point, a current is

1 applied to nucleation layer 90 effective to electrodeposit a layer 94,
2 such as electroless deposited copper, to a thickness of 1 micron. Resist
3 blocks 92 effectively insulate underlying nucleation layer 90 from
4 depositing copper atop the resist. An example voltage and current
5 would be 5V and 1 milliamp, respectively.

6 Referring to Fig. 17, the resist is then stripped from the
7 substrate. A dry plasma etch is then conducted which selectively
8 removes the exposed nickel nucleation layer 90 relative to copper layer
9 94, such that only copper over the illustrated nickel remains. Then if
10 desired and as shown, current is applied to the nucleation layer and
11 copper material in a manner and under conditions which electroless
12 deposits a 2000 Angstrom thick layer 96 of, for example, platinum,
13 palladium or iridium. Wire bonding could then be conducted apart
14 from apexes 43a utilizing an intervening block of aluminum.

15 Such technique is preferable to the previously described electroless
16 deposition method in that lower voltage and current can be utilized in
17 the electroless deposition method where a highly conductive nucleation
18 layer is provided atop the substrate.

19 Another alternate and preferred technique for forming and
20 rendering the projecting apexes conductive is shown with reference to
21 Figs. 18 and 19. Such is an alternate construction corresponding to
22 that construction shown by Fig. 10. Fig. 18 is the same as Fig. 10,
23 but for the addition of, a) an insulating layer 71, preferably SiO_2 ; and
24 b) a metal nucleation layer 73, prior to the providing and patterning

1 to produce photoresist blocks 68. Such a process is preferable to that
2 shown by Fig. 10 to provide separation of the typical monocrystalline
3 silicon substrate 12 from direct contact with metal. Fig. 19 illustrates
4 the subsequent preferred electroless deposition of a metal layer 72 using
5 substrate nucleation layer 73 as a voltage source. With respect to the
6 embodiment shown by Figs. 15 - 17, such also would preferably be
7 provided with an insulating layer prior to deposition of the nucleation
8 layer. An alternate and preferred material for layer 73 would be
9 aluminum metal, with the subsequently electroless layer being comprised
10 essentially of platinum. Platinum could then be used as a masking
11 layer to etch exposed aluminum after photoresist strip. An example
12 etch chemistry for such etch would include a wet H_3PO_4 dip.

13 In compliance with the statute, the invention has been described
14 in language more or less specific as to structural and methodical
15 features. It is to be understood, however, that the invention is not
16 limited to the specific features shown and described, since the means
17 herein disclosed comprise preferred forms of putting the invention into
18 effect. The invention is, therefore, claimed in any of its forms or
19 modifications within the proper scope of the appended claims
20 appropriately interpreted in accordance with the doctrine of equivalents.
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